# Modelling of Single Crystal Diamond Schottky Barrier Diodes for High Voltage Applications

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**Abstract** A detailed description of transport physics in ultra high quality synthetic single-crystal (SSC) diamond layers is presented here for the first time. No numerical model detailing carrier transport in diamond devices is available as yet. This model is analysed with respect to a 10μm diamond Schottky barrier diode (SBD) in the 2D MEDICI device simulator where the numerical results obtained were compared to those obtained experimentally.

**Device description and models used** The diode structure comprises of a 10 μm drift region made of intrinsic *i* diamond, grown on a highly boron doped p-region, with a gold Schottky cathode (workfunction 4.9eV). This layer holds off the reverse voltage in the blocking mode and thus can be made very thin. In addition, diamond has the highest breakdown electric field, thus making it an ideal candidate for power applications, although the ultimate breakdown capability of diamond power devices is limited by their termination structures rather than the *i* layer thickness. This layer has space charge limited-like conduction across it during the on state, thus charge transport across it must be well understood to accurately model the behaviour of power devices. The *i* layer is implemented as a lowly doped $N_I$ layer in the numerical model to aid numerical convergence as this prevents excessively low carrier count during conduction. Boron forms a deep donor in diamond, thus not fully activating all carriers at low concentrations. The model proposed incorporates these observations as well as temperature dependence, and transition to fully activated metallic conduction for concentrations > $10^{17}$cm$^{-3}$. Concentration dependant mobility is invoked by implementing two models based on the 3800cm$^2$/V-s high intrinsic layer hole mobility in [1,2] and $N_I^{-1}$ trends in [3] as shown in Fig. 1. In addition, the $T^{-1.5}$ and $T^{-3.7}$ temperature dependence of mobility for 300K < $T$ < 380K and 400K < $T$ < 540K respectively [2] is incorporated into the model to take into account the influence of temperature on device performance [4]. Impact ionization coefficients catering to device breakdown have yet to be described for diamond. The model proposed describes these parameters by adjustment of parameters used for SiC on the basis of the 5.45 eV band-gap of diamond [5].

**On-state matching** Fig. 2 shows the measured on-state characteristics of the oxygen terminated diamond SBD at 30°C. The potential barrier at the cathode was adjusted to that seen by experiment (~ 2V) due to the inability to model accurately the experimental Schottky barrier where interface traps and surface states result due to surface roughness and contaminants, leading to a change in the barrier potential. From the plot, it can be seen that by invoking the Nebel mobility trends [3] and the high hole mobility of 3800cm$^2$/V-s reported by Isberg [1,2], there is a good fit between the experimental and numerical data, for $N_I$ concentrations between $10^9$ and $10^{11}$cm$^{-3}$. From Fig. 2, it can be seen that there is a mere 2% difference (at $V_A$ = 3V) between the numerical and experimental results for the practical forward voltage range (2V + turn-on voltage) over which an SBD would be expected to operate. The experimental *I-V* curve shows more pronounced superlinear behaviour than the simulated curve at higher bias. This is due to the approximation of the intrinsic layer with a lowly doped ($10^{11}$cm$^{-3}$) layer in the simulations which cannot account for space charge limited transport. For a first attempt at modelling SSC diamond SBDs, this is a remarkable result as it verifies the 'idealness' of SSC diamond obtained by CVD. It is expected that the match shown here would be similar at higher temperatures once the model describing the mobility dependence of temperature (and doping) has been completely parameterised and optimised [6].

**Reverse blocking behaviour** The numerical reverse characteristics of the diode show a breakdown voltage of 2.1kV, the point of breakdown being at the quasi-*i*/p$^+$ bulk junction. The plot of electric field through the device indicates a field of 2.2MV/cm being supported by the quasi-*i* layer. The experimental breakdown voltage obtained was larger. This difference is due to the approximation made for the voltage blocking *i* layer in the device model as well as the extrapolation of impact ionization parameters from that of SiC.

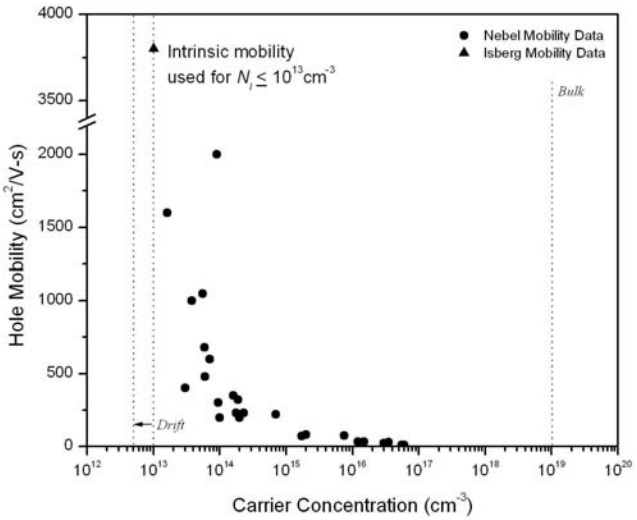


Fig. 1. Carrier concentration dependant hole mobility available in literature [1], [2]. A composite mobility model between the two was also used in the numerical investigation.

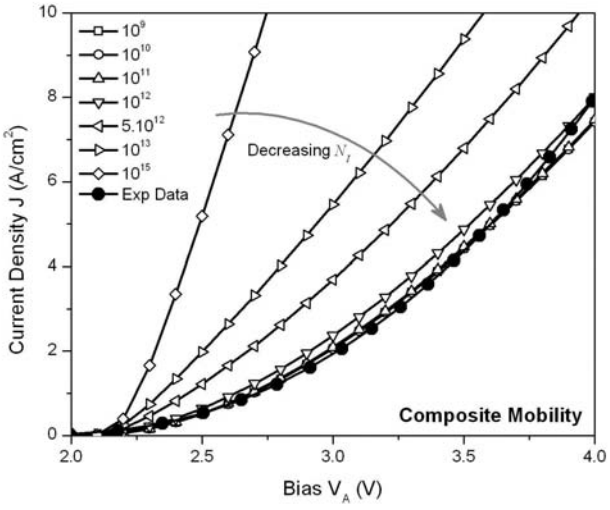


Fig. 2. Numerical and experimental forward characteristics of the $i/p^+$ diamond SBD. The numerical curves shown here were calculated with various $N_I$ indicating that boron doping between $10^9$ – $10^{11}$cm$^{-3}$ would be a good approximation to an *i* layer. The fit is close to perfect.

**References**


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